EVALUATION AND ANALYSIS OF ADJUSTMENTS ALTERNATIVES FOR ENERSUL'S PROTECTION SYSTEM IN LOW LOAD DENSITY REGIONS

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ABSTRACT

This paper deals with protection of primary networks that supply rural areas. It focuses on the main issues that characterize the power supply of these particular areas, such as feeders with a considerable length, very long single phase tappings in a ground-return configuration, low short-circuit power, low load density and high degrees of load unbalance.

Specific studies, regarding the analysis of conventional protection schemes for these particular areas and for feeders of three substations that supply regions with these characteristics, are presented in this paper. Based on the results of these studies, a few actions are indicated, in order to mitigate the problems caused by high impedance faults in rural area and improve the performance of protection tripping and fault detection.

INTRODUCTION

Enersul – Energy Corporation of Mato Grosso do Sul – is an important power distribution utility in Brazil. It supplies around 92% of Mato Grosso do Sul state, corresponding to approximately 670 thousand customers.

ENERSUL's power networks that supply rural areas are mainly composed by feeders with considerable length and very long single-phase with ground return (SGR) tappings.

There are two fundamental topics regarding the protection adjustment of ENERSUL's primary feeders that supply rural areas:

- The reduced short-circuit Power in the respective Power distribution system;
- The predominance of soils presenting an electric resistivity that is superior than regular levels, leading to "high ground impedance faults".

Thus, the magnitude of the short-circuit current resulting from a single phase-to-ground fault tends to be lower than the magnitude of the current that corresponds to the feeder's normal load condition. Such behavior does not let conventional protection devices to operate properly, according to the traditional over-current principle.

There another issue to be considered regarding the operation of ENERSUL's power distribution system. The considerable unbalance condition of some feeders is also a problem for an effective protection adjustment, since the neutral pickup currents are set to a level that is higher than the one usually considered.

In this context, this paper deals with the following topics:

- SGR configuration for power distribution systems;
- High impedance short-circuit characterization;
- Load flow and short-circuit models that are in agreement with suitable representation of SGR tappings;
- Fault impedance evaluation;
- Evaluation of practical cases.

SGR DISTRIBUTION SYSTEM CONFIGURATION

SGR distribution system configuration is economically useful for supplying low density regions, because such configuration does not require the neutral conductor.

So, the return path for the electric current is made through the ground, considering the grounding system from the single-phase transformers.

The SGR system may present different configurations, such as [2]:

- One-line;
- One-line with isolation transformer;
- Partial neutral.

The one-line configuration is for SGR system commonly used when the secondary side of the substation transformer presents grounded-star connection. This configuration is the most used one in ENERSUL's distribution system.

HIGH IMPENDANCE SHORT-CIRCUIT

The high impedance short-circuit depends on some external aspects, such as: humidity, temperature, soil nature, contact extension between the phase conductor

and the ground, contact characteristics (conductor's dynamism over the soil), phenomenon duration, among others.
According to Moreto [7], although it is very hard to generalize (due to the randomness of the phenomenon) high impedance faults present some basic characteristics: Non-linearity (i.e., non-purely sinusoidal), due to the electric arc (characterizing the signal through the fundamental and some harmonic components); Current peaks' random variation; Asymmetry between the positive and negative cycles.
In this context, the vast majority of the protection devices developed for this type of phenomenon (high impedance relays) is based on the qualitative characteristics of the short-circuit current signal, including the arc electric composition [1].
Among the techniques available in the literature for detection of high impedance faults (some of them are already implemented in the logic of high impedance relays), we can list: Specialist systems based on the induction principle; Decomposition of the short-circuit current through the Wavelet Transform; Heuristic models based on decision trees; Models based on Fuzzy Logic; Voltage unbalance monitoring; Models based on artificial neural networks; Analysis of the electric arc and its harmonic content [6].

ELECTRIC MODEL

An electric model was conceived, allowing one to deal with unbalance three-phase Power distribution systems with tappings in SGR configuration.
The model can be summarized through the following topics [3]:

a-) Network Modeling:

- Representation of generators and single-phase, two-phase loads or three-phase loads (loads can be modeled as constant power, current or impedance with respect to the voltage).
- Representation of 4-wire networks, considering the networks sections modeled through the PI-model.
- Representation of the medium voltage grounding (which is necessary, in order to model the SGR tappings).

b-) Linear system solving:

- The Gauss Elimination Method was used to find the solution for the load flow and the short-circuit simulations through the nodal admittance matrix (iterative process).

GROUNDING IMPEDANCE MEASUREMENTS

Volt-Ammeter Modification

Using a Megger for measuring the grounding impedance, was proposed a modification was made in order to reproduce a single phase-to-ground short-circuit [2].

Two different tests were carried out. The results were used to determine the value for the fault impedance of a single phase-to-ground short-circuit. A 4/0 CA cable was used for the tests.
The first test was executed in the area close to the mini outer road ring in Campo Grande, between the exits for the cities of Dourados and Três Lagoas, during the morning and in very hot and dry period. The characteristic data for this test is summarized as follows:

- Date of execution: 27/Nov/2008.
- Period of the day: Morning.
- Soil type: Sandy Clay.
- Environment Temperature: 35 ºC
- Contact extension: 84 meters

Figure 1 illustrates the conductor used for single phase-to-ground short-circuit simulation test. Figure 2 illustrates the device used for the measurements ("Megger").

Figure 1 - Conductor used for short-circuit simulation test

Figure 2 – Measurement Device ("Megger")

Four different measurements were executed. The position for the potential stem was changed, in order to check its influence in the fault impedance result. It presents a very small range, varying from 1.477,0 Ω to 1.510,0 Ω.
The second test was executed in a training field close to ENERSUL's head office during the afternoon of the same day in a dry and also very hot environment. The characteristic data for this test is summarized as follows:

- Period of the day: afternoon;
- Soil nature: Grass and sandy clay;
- External temperature: 28 ºC.

The cable and extension contact were the same from the previous test. Four different measurements were also executed during this test and the potential stem position was also changed. The measured values did not change significantly either, varying from 1,536Ω to1,591Ω.

Field Test: Phase Conductor Falling on the Ground

A short-circuit field test were carried out, i.e., in test a single phase-to-ground fault was caused following specific procedures that enabled the fall of a energized phase conductor of a feeders on to the ground [5].

The tests were executed by COELBA – Electricity Company from Bahia State – which is the largest Power distribution utility in Brazil's northeast region. The authors were authorized by COELBA to follow the tests execution closely.

The place chosen for the tests execution was a region located at the farthest point of the third feeder from the substation of Aratu's industrial center (CIA), in which the interdiction is easier to be executed.

The voltage level is 13.8kV and the supplied load was balanced and around 3.92MVA. The distance between the substation and the tests' location is 12km approximately. A 6K fuse was installed in the branch line where the short-circuit tests were carried out. All the tests were executed in 06/Aug/2009.

In one of the tests, three concrete boards were placed onto the wet ground. When the energized conductor touched the ground, the fuse burnt out, which did not characterize high impedance short-circuit.

In another test, a surface filled with gravel (around 5cm of depth) was adapted over the wet ground. The contact's duration was superior to 3 minutes. An electric arc occurred, vitrifying the gravel and causing the loss of part of the cable through diffusion. The electric current recorded was around 9 A and it was not sensed by the protection devices. Figure 3 illustrates the electric arc occurrence in this test.

Figure 3 – Electric arc

The occurrence of high impedance short-circuits without the proper operation of the conventional protective relays involved is illustrated by this last test.

CONVENTIONAL PROTECTION ASSESSMENT

Specific high impedance events inside ENERSUL´s concession area were studied in 2009, giving special attention for those verified in São Gabriel D'Oeste, Coxim, Costa Rica, Bataiporã e Jardim [4].

A remarking characteristic of these events was related with the qualitative evolution of the short-circuit. They presented a high initial current (which may cause the protection to trip and lead to a sequence of reclosing actions) with a considerable reduction in its magnitude in short period of time (due to soil vitrification caused by the electric arc, which suddenly elevates the fault impedance value). Thus, the short-circuit current will be extremely low which is not enough to trip the protection.

CASE STUDY

Based on the results of short-circuit studies for rural areas, different computational tools were developed and, then, aggregated in a software for the analysis of protection systems for power distribution networks, namely Interprote.

Interprote was used in a study that considered 9 feeders from 3 substations that supply rural areas [3]. The voltage level for all feeders is 13.8kV.

Table 1 shows some of the relevant parameters considered in the analysis for each one of the 9 feeders.

Table 1: Data from the Assessed Feeders

Substation (a)	Feeder (B)	L (km) (c)	S (MVA) (d)	D (km) (e)
Aquidauana	AQU-01	669.4	4.69	93.6
	AQU-02	1,174.2	2.81	169.8
	AQU-03	120.1	6.54	33.2
	AQU-04	252.9	5.78	51.4
Coxim	MIM-01	1,004.8	0.57	122.6
Mimoso	COX-01	76.7	3.83	21.5
	COX-02	808.9	1.14	109.7
	COX-03	750.0	1.66	123.9
	COX-04	33.8	5.50	8.0

Note: Table 1 has the following terms in its columns:

(a) Supply substation.

(b) Feeder code.

(c) Feeder's total length (km).

(d) Maximum Apparent Power Demand from the feeder.

(e) Electric distance (km) between the source and the most distant bus.

The study consisted on the simulation of singe phase-to-ground short-circuits for each feeder. The bus considered for the short-circuit occurrence was the furthest one, with respect to the source. The conditions for the protective devices operation towards the possibility of high impedance fault occurrence were evaluated.

Table 2 summarizes the results obtained for each feeder.

Table 2: Data from the Assessed Feeders and Results Obtained

Feeder (I)	I adjust. 1 (A) (II)	I adjust. 2 (A) (III)	Impedance (Ω) (IV)
AQU-01	60.0	12.0	466.0
AQU-02	60.0	12.0	365.0
AQU-03	60.0	60.0	82.0
AQU-04	120.0	20.0	311.0
MIM-01	20.0	15.0	279.0
COX-01	60.0	60.0	101.0
COX-02	60.0	12.0	497.0
COX-03	20.0	15.0	330.0
COX-04	60.0	60.0	125.0

Note: Table 2 has the following terms in its columns:
(I) Feeder code.
(II) Pickup neutral current for the main protective device (relay or circuit-breaker installed at the substation bus).
(III) Pickup neutral current for the recloser that is closest one to the fault location.
(IV) The fault impedance value that would lead to a short-circuit (single phase-to-ground) current that is higher than the pickup neutral current adjustment.

Regarding the adjustment for the protection systems, the configuration of the neutral current value in the main device (device at the substation bus) is a notable aspect, which may vary from 20A (as in MIM-01 and COX-03) to 120A (as in AQU-04).

Generally, when the value for the fault impedance is fixed at 40Ω (which is the reference value in the electrical sector, regarding single phase-to-ground fault simulations), it is possible to enable the protective devices' operation for all 9 feeders.

Considering the possibility of high impedance fault occurrence and the critic zone for the fault impedance values up to 82Ω (which corresponds to 105% above the fixed value of 40Ω), the protective devices would still operate for all 9 feeders.

For 6 of the 9 feeders (AQU-01; AQU-02; AQU-04; MIM-01; COX-02 e COX-03), the results indicate that the network impedance is predominant with respect to the contact one, since the maximum fault impedance values are considerably higher than the adopted reference. Such aspect is compatible with the long length of these feeders.

In this context, the study indicates that plausible directives may be adopted, giving special highlights for the following actions:

a-) Reducing the load unbalance, which would change the value adjusted for the neutral protection to lower levels.

b-) Increasing the short-circuit power. Installing isolation transformers at strategic points in a compatible manner with respect to the SGR systems is an alternative for increasing the short-circuit power.

c-) Using alternative protective devices, especially high impedance relays, based on the fault identification through qualitative aspects present in the electric signals (harmonic content, electric arc, unbalance monitoring, among others).

d-) For the feeders that present a high frequency of high impedance faults, an alternative would be favoring the fuse burning instead of the operation of reclosers and relays. Normally, before the first *trip*, the fault does not characterize a high impedance fault, and may evolve to this condition.

CONCLUSION AND FINAL COMMENTS

The main topics related with the analysis of protection for primary networks were addressed in this paper.

The main supply characteristics of the areas involved and particularities from ENERSUL's distribution system were highlighted.

In this context, specific analysis regarding the electric model, the short-circuit characterization, single phase-to-ground short-circuit field tests and grounding impedance measurements (through the modification of the classic Volt-ammeter method) were carried out. According to the last one, one could notice the possibility of obtaining an extremely high value for the grounding impedance

Analyses of the conventional protection schemes from the feeders that supply rural part of ENERSUL's concession area were also executed.

Some mitigation actions were suggested, in order to decrease the impact of problems caused by high impedance short-circuits and improve the performance of protective devices' operation and fault detection.

The topics addressed and the set of computational tools developed in this paper compose a relevant contribution to the analysis of high impedance fault, which is probably one of the most complex topics regarding the analysis of primary networks protection.

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